Acoustic Noise Control Plan

Fluids and Combustion Facility

Rev. A
Final

October 27, 2000

AUTHORIZED by CM when under FORMAL Configuration Control	
Date	Signature
10/28/00	*/s/ Robert H. Van Niel*

Prepared For:
National Aeronautics and Space Administration
John H. Glenn Research Center
Microgravity Science Division
Cleveland, Ohio 44135

Prepared By:
Federal Data Corporation
Under Contract NAS3-99155
2001 Aerospace Parkway
Brook Park, Ohio 44142

PREFACE

The National Aeronautics and Space Administration (NASA) is developing a modular, multi-user experimentation facility for conducting fluid physics and combustion science experiments in the microgravity environment of the International Space Station (ISS). This facility, called the Fluids and Combustion Facility (FCF), consists of three test platforms: the Fluids Integrated Rack (FIR), the Combustion Integrated Rack (CIR), and the Shared Accommodations Rack (SAR). This document defines the methodology that will be used to sub-allocate the acoustic noise limits to subrack components; provides a plan for controlling the noise emission of each component and the rack as a whole; describes the technical approach for analysis and verification and the acoustic data that will be submitted; and describes the recovery plan to be followed if the measured noise levels exceed the requirements.

ACOUSTIC NOISE CONTROL PLAN
FOR THE
FLUIDS AND COMBUSTION FACILITY

Prepared By: *_/s/ Eugene A. Krejsa_________* **Date:** *_10/26/00_____*
Eugene A. Krejsa
Aeroacoustic Consultant
Combustion Integrated Rack Development Program
Independent

Reviewed By: *_/s/ William Quinn_________* **Date:** *_10/26/00_____*
William Quinn
Product Assurance Manager
Fluids and Combustion Facility Development Program
Hernandez Engineering Incorporated

Approved By: *_/s/ Jon Wetherholt_________* **Date:** *_10/27/00_____*
Jon Wetherholt
Product Development Team Lead
Combustion Integrated Rack Development Program
Analex Corporation

Concurred By: *_/s/ Andrew M. Peddie_________* **Date: :** *_10/27/00_____*
Andrew M. Peddie
FCF Deputy Director
Federal Data Corporation

Concurred By: *_/s/ Christopher J. Pestak_________* **Date: :** *_10/27/00_____*
Christopher J. Pestak
FCF Director
Analex Corporation

REVISION PAGE
ACOUSTIC NOISE CONTROL PLAN

Revision	Date	Description of Change or ECO's/ECP's Incorporated	Verification and Date
Final	09/21/00	Initial	
A	10/27/00	Revise Figure 1	10/27/00

TABLE OF CONTENTS

LIST OF APPENDICES

LIST OF TABLES

LIST OF FIGURES

1.0 INTRODUCTION

1.1 Scope.

The Acoustic Noise Control Plan (FCF-PLN-0023) presented herein provides a detailed description of the process that will be used to ensure that the noise levels within the ISS, resulting from any one rack within the FCF, will be at or below required levels as specified in the CIR, SAR, and FIR requirements. This plan defines the methodology that will be used to sub-allocate the acoustic noise limits to subrack components; provides a plan for controlling the noise emission of each component and the rack as a whole; describes the technical approach for analysis and verification and the acoustic data that will be submitted; and describes the recovery plan to be followed if the measured noise levels exceed the requirements.

1.2 Purpose.

The goal of the plan presented herein is to achieve a noise environment within the ISS that will comply with the system requirements and will result in an environment that will minimize communication difficulties, concentration problems, sleep interference, and the possibility of temporary or permanent hearing loss. To achieve this goal, each integrated rack within the ISS must meet noise requirements significantly below those for the ISS as a whole. Likewise, each component within a rack needs to be sufficiently below the required level for the rack, such that the total noise of the rack meets the requirement. In particular, the purpose of this plan is to ensure that each integrated rack within the Fluids and Combustion Facility will be at or below required levels.

While goals can be set for components within a rack, such that the total level associated with those goals fall within the requirement, these goals are meaningless unless they can be achieved with reasonable cost, volume, and weight penalties. Thus, the subrack allocation of the noise requirements is a balance between the arithmetically inferred goals and engineering reality. Quiet components should be included in the initial design of the hardware to minimize conflict between requirement and actual hardware in the racks. This plan outlines the process that will be followed to provide rack and rack component designs, which result in noise levels that fully comply with requirements.

Although the goal of this plan is to achieve a design that meets the required noise levels and demonstrates that compliance during verification testing, the possibility exists that demonstration testing will show that the design does not meet the requirements. The final portion of this plan outlines a recovery plan to achieve compliance with the requirements should initial verification testing show that requirements are exceeded. A key part of that recovery plan is to obtain sufficient detailed acoustic data during verification testing to allow for the reasons for exceeding requirements to be determined such that corrective actions can be taken in an efficient and timely manner.

A Microgravity Control Plan (FCF-PLN-0037), written concurrently with the Acoustic Noise Control Plan, documents the related Microgravity testing and control. Microgravity disturbances are broken down into three different categories: Quasi-Steady, vibratory, and transient. Quasi-

Steady disturbances include the frequency range below 0.01 Hz; vibratory covers the frequency range between 0.01 and 300 Hz; and transient covers the peak forces, which include impulse forces, applied to the rack. To summarize, the microgravity frequency range is from 0.01 Hz to 300 Hz. Acoustic requirements cover a range of frequencies from the 64 Hz octave band to the 8000 Hz octave band. At some frequencies the acoustics and microgravity disturbances overlap. When designing for acoustics, one should be aware that microgravity disturbances could still exist. For example, while potentially beneficial for acoustics, lowering the frequency of a noise source to below 300 Hz could cause microgravity disturbances since the lower microgravity requirement's range is below 64 Hz.

1.3 Flow chart.

A flow chart for the Acoustic Noise Control Plan is presented in Figure 1. The first step in the noise control process will be to assess component and rack noise levels and then determine noise goals for individual components such that the total rack complies with requirements. The noise control process will include an allotment for the Principle Investigator (PI) package because the noise requirements treat the rack as a whole. The PI will be responsible for conformance to stated noise requirements and for verification of his package. Component and rack design modifications will be made as required. Initial acoustic testing will be performed to verify rack compliance. If the rack does not show compliance, further diagnostic test will be performed to aid design modifications. Final acoustic testing will be conducted to verify compliance.

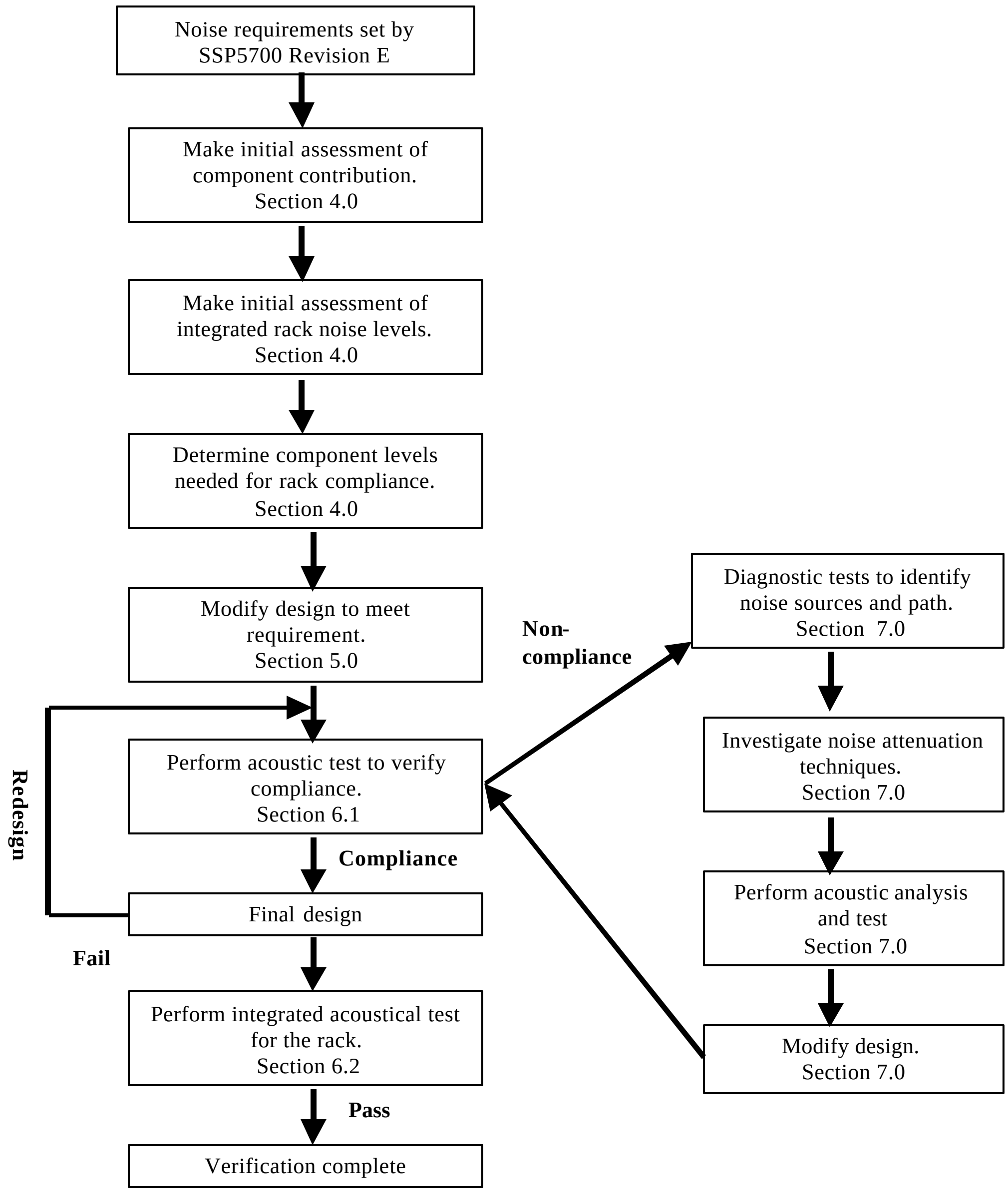


FIGURE 1. Flow chart for Acoustic Noise Control Plan

2.0 DOCUMENTS

This section lists specifications, models, standards, guidelines, handbooks, and other special publications. These documents have been grouped into two categories: applicable documents and reference documents.

2.1 Order of precedence for documents.

In the event of a conflict between this document and other documents referenced herein, the requirements of this document shall apply. In the event of a conflict between this document and the contract, the contractual requirements shall take precedence over this document. All documents used, applicable or referenced, are to be the issues defined in the Configuration Management (CM) contract baseline. All document changes, issued after baseline establishment, shall be reviewed for impact on scope of work. If a change to an applicable document is determined to be effective, and contractually approved for implementation, the revision status will be updated in the CM contract baseline. The contract revision status of all applicable documents is available by accessing the CM database. Nothing in this document supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.2 Applicable documents.

The documents in these paragraphs of the latest revision or issue are applicable to the FCF Project to the extent specified herein.

FCF-SPEC-0001 Rev.: 6.0 10/00	System Specification International Space Station Fluids and Combustion Facility
FCF-DOC-002 Rev. A, 4/99	Science Requirements Envelope Document – Fluids and Combustion Facility
SSP 57000 Revision E	Pressurized Payloads Interface Requirements Document, International Space Station
SSP 57010B 5/00	Pressurized Payloads Generic Payload Verification Plan Appendix D, Acoustic Noise Control Plan for ISS Payloads
PIRN No. 57000-NA-0208 approved 5/2/00	Refine (Relax) Intermittent Noise Limit Durations

2.3 Reference documents.

The documents listed below are provided only as reference material for background information and are not imposed as requirements.

1. Beranek, Leo L., ed., Noise and Vibration Control McGraw-Hill Book Co., 1971.
2. NASA SP-5108 “Handbook For Industrial Noise Control.”
3. “Design for Low Noise Emission,” David A. Nelson.
4. ANSI S12.35-1990 “American National Standard Precision Method for the Determination of Sound Power Levels of Noise Sources in Anechoic and Hemi-Anechoic Rooms.”

3.0 SYSTEM DESCRIPTION

The Fluids and Combustion Facility (FCF) is a permanent on-orbit research facility located inside the United States Laboratory Module (US Lab) of the International Space Station (ISS). The FCF is designed to accommodate and facilitate microgravity fluid and combustion science experimentation on the ISS. The FCF consists of three racks: the Combustion Integrated Rack (CIR), the Fluids Integrated Rack (FIR), and the Shared Accommodation Rack (SAR). Both the FIR and the CIR must be capable of operating independently or in conjunction with added services provided by the SAR. The Environmental Control System (ECS) is comprised of four major subsystems that control the thermal environmental, fire detection and suppression, nitrogen gas interface to the ISS, and vacuum exhaust interface to the ISS. The Air Thermal Control Unit (ATCU) removes waste thermal energy from the internal atmosphere of all three FCF racks. The ATCU functions along with the Water Thermal Control System (WTCS) to provide rack cooling. Both the ATCU and the WTCS are part of the ECS. Each rack will be equipped with an ATCU for thermal control.

A preliminary Acoustic Timeline for the FCF is shown in Appendix B. The timeline shows FCF rack components that are noise sources and when they will operate.

3.1 Combustion Integrated Rack (CIR).

The purpose of the CIR is to provide the majority of the services required to conduct combustion science research in the extended microgravity conditions on board the ISS. The remainder of the equipment will be furnished by the individual payload packages that will fit into the Experimental Mounting Structure inside the combustion chamber of the CIR. Major elements/subsystems of the CIR, shown in Figure 2, include: the fuel/oxidation management assembly (FOMA), the combustion chamber, the optic bench, the experiment specific chamber insert, the input/output processor (IOP), the environmental control system (ECS), the active rack isolation system (ARIS), science diagnostics equipment, image processing packages (IPP), the electric power control unit (EPCU), and a laptop computer.

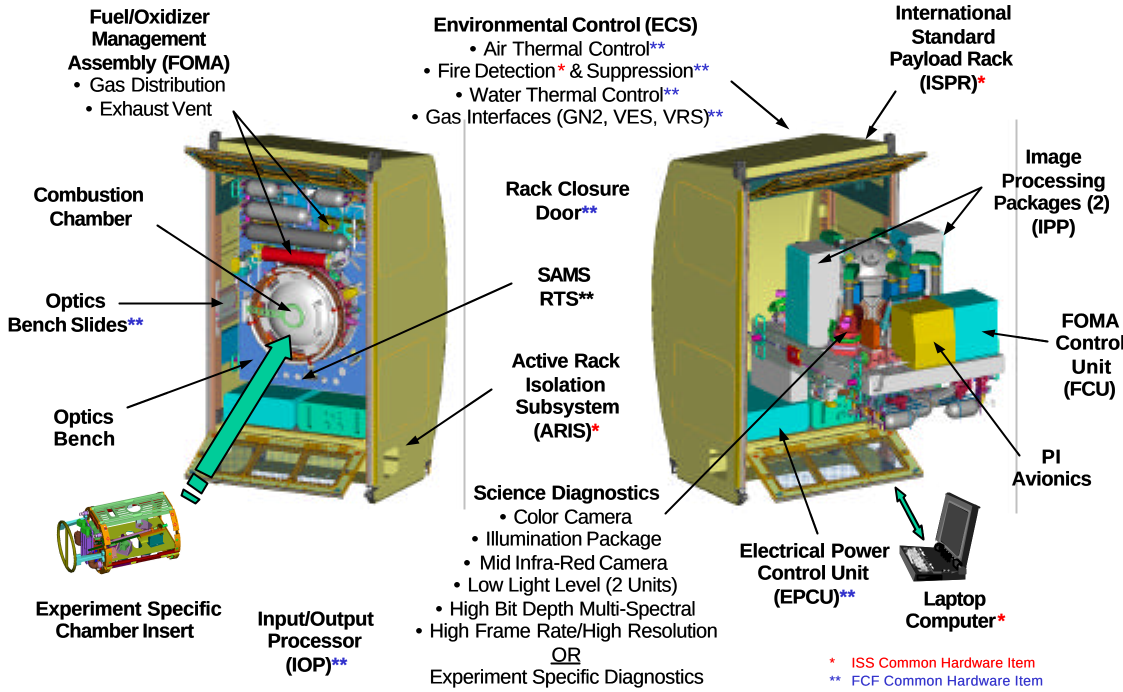


FIGURE 2. Combustion Integrated Rack

3.2 Fluids Integrated Rack (FIR).

The purpose of the FIR is to provide accommodations required for fluid physics and dynamics experimentation and support the conduct of science by payload equipment placed within it. Major elements/subsystems of the FIR, shown in Figure 3, are: electric power and control unit, input/output processor, cameras, image processing package, optical components, fluids science avionics package, illumination and laser packages, active rack isolation system, and the environmental control system.

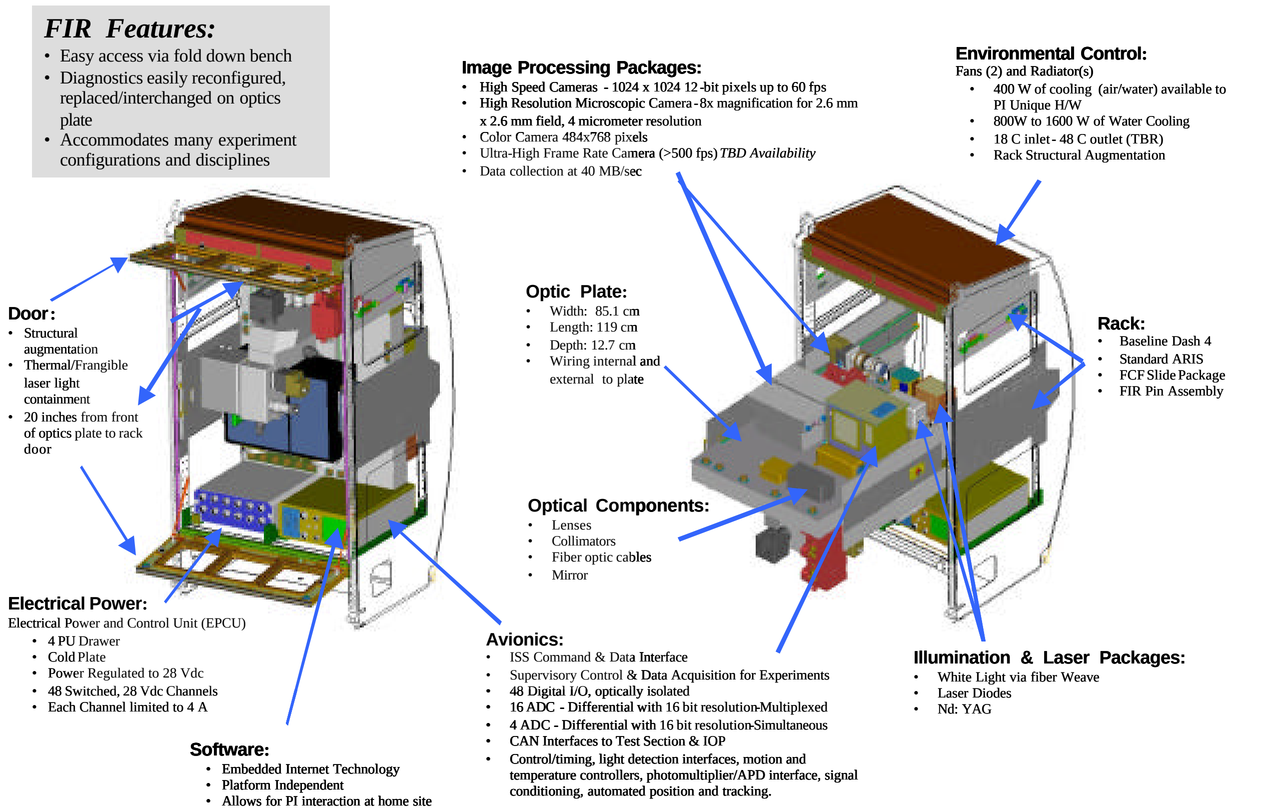


FIGURE 3. Fluids Integrated Rack

3.3 Shared Accommodation Rack (SAR).

The SAR supports both the CIR and the FIR with equipment, such as image acquisition and processing computers, mass data storage, removable storage media, and post processing computers. In addition, the SAR (Figure 4) may accommodate small experiment packages, commercial and international payloads, and a subset of the fluid physics basis-type experiments.

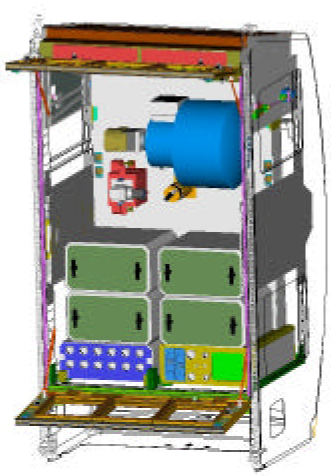
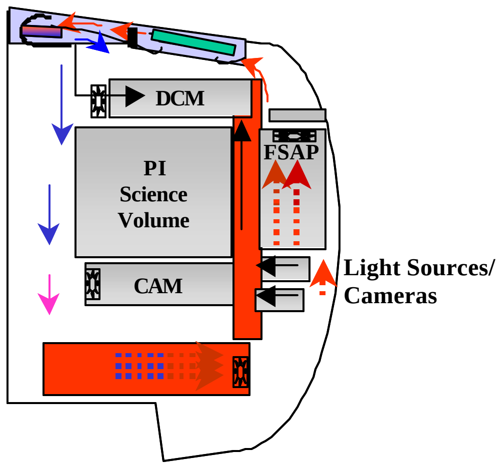


FIGURE 4. Shared Accommodations Rack

3.4 The ATCU: Cooling designs for the FIR and the CIR Racks.

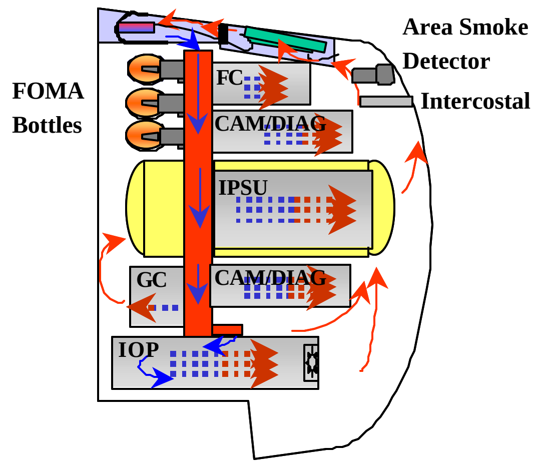
The ATCU contains air-cooling hardware and is positioned at the top of each rack. The design includes isolation springs between the fan housing and the frame attachment and a layer of sorbithane to minimize structure borne noise and to dampen resonances. Two centrifugal fans draw warm air through a particulate air filter and direct the air to an air to water heat exchanger. In the FIR, cool air flows into the front of the rack volume and is drawn into plate-mounted electronic components. Exhaust flow is drawn through ports on the bench and carried to the rear of the ATCU. In the CIR, cool air flows out of the ATCU into ports in the top of the optic bench. The air flows through the optic bench and exits at the Universal Mounting Locations (UML) and ports for the gas chromatograph and IOP to cool electronics in the rack. Seals at all optic bench air inlets and exits channel cooling air through the optic bench. The orifice size of exit ports ensures proper airflow to bench-mounted electronics and to the IOP. The airflow paths are shown in Figure 5. The air-cooling design for the SAR is not fully developed at this time but is expected to be similar to what is shown for the FIR. Noise attenuation or enhancements due to airflow path and pressure drops within each rack will be assessed. Noise resulting from the ATCU in the CIR, FIR, and SAR will be included in each rack's total noise.

Forced Air/Bench Suction



Present FIR and SAR Air Cooling Design

Forced Air Through UML's



Present CIR Air Cooling Design

FIGURE 5. Present air cooling design for FIR, SAR, and CIR

4.0 METHODOLOGY FOR SUBRACK ALLOCATION

This section describes the process that will be used to set noise goals for individual components within a rack such that the total noise generated by the rack will be at or below the required levels. The required noise levels for the total rack are defined in SSP 57000, Revision E. The limits for continuous noise sources and intermittent noise sources at 0.6 m from the test article are defined by NC-40 and are summarized in the following tables:

TABLE I. Rack noise limits for continuous noise sources at 0.6 m from the noisiest part of the article (for rack testing)

Frequency	63	125	250	500	1000	2000	4000	8000
SPL	64	56	50	45	41	39	38	37

TABLE II. Rack noise limits for intermittent noise sources at 0.6 m from test article

This chart reflects changes made by PIRN No.57000-NA-0208 approved 5/2/00.

Maximum Rack Noise *Duration Per 24 Hour Period	**Total Rack A-weighted SPL (dBA)**
8 Hours	49
7 Hours	50
6 Hours	51
5 Hours	52
4.5 Hours	53
4 Hours	54
3.5 Hours	55
3 Hours	57
2.5 Hours	58
2 Hours	60
1.5 Hours	62
1 Hour	65
30 Minutes	69
15 Minutes	72
5 Minutes	76
2 Minutes	78
1 Minute	79
Not Allowed	80

* The Rack Duration is the total time that the rack produces noise above the NC-40 limit during a 24 hour time period.

The first step in this process to sub-allocate the limits described above to individual components within a rack is to identify those components believed to be significant contributors to the total noise of a rack. Once these components have been identified, the noise properties of these components will be established. The desired properties of these components include octave band noise levels, time and length of operation, and location within the rack. While not all of these properties will be available to the degree of accuracy required for verification, it is the objective of this activity to assess the noise levels with sufficient precision so that an overall assessment of the severity of any noise problem can be made and to set the realistic noise goals for these rack components. Since many of the component noise levels are likely to be isolated levels, estimates of the effect of the surrounding enclosure on the resultant noise levels and transmission losses through the surrounding rack structure are also needed. For the purpose of setting noise goals for individual components, all fans, motors, pumps, disk drives, flow valves, and fluid flows (both water from the WTCS and gas from the ATCU and the FOMA) will be considered as potential noise sources.

If no initial noise data is available, an initial noise goal can be set by using the following formula:

Component noise goal = Rack noise goal – 10log(Number of Major Sources) – 3 dB

Where a 3 dB margin is included to provide design margin and to allow for the contribution of all the minor sources.

This is a very crude budgeting process, which ignores the fact that noise reduction may be very difficult to obtain for some components and fails to take advantage of the fact that noise reduction may be easy for other components. A more sophisticated approach would be to make initial estimates of noise levels of the various components. These estimates would be made from existing data on the components or similar components. The estimates will be augmented with new data obtained from the actual components. While ideal conditions may not be available to obtain these data, efforts will be made to minimize background levels and reverberation effects. Corrections for background will be made. If the noise levels are from isolated components, estimates of the effect of the surrounding rack enclosure and of the transmission loss will be used to determine the noise emission. These noise emission estimates and data will be used to construct the total rack noise signature (i.e. octave band noise levels) as a function of time and operating mode. The total sound pressure level within each octave band will be calculated using the following equation:

$$SPL_{TOTAL} = 10*LOG_{10}(10^{SPL_1/10} + 10^{SPL_2/10} + 10^{SPL_3/10} + 10^{SPL_4/10} + 10^{SPL_N/10})$$

A-weighted levels will be computed by applying the appropriate A-weighting to each band and then computing the A-weighted total. Comparison of these total octave band and dBA levels rack estimate with the noise requirements will be made for both continuous and intermittent noise sources. If these total rack noise estimates exceed the required levels, the required level reductions of individual components will be obtained.

For continuous noise sources, the required reductions will be determined for each octave band by reducing the level of the loudest component until its levels reaches that of the next loudest component. Then the level of those two components will be reduced to the level of the next loudest component. This process will be continued until the total level is at or below the required levels. This process will establish the initial goals for the individual components as a function of frequency. A review of these goals will then be made to assess the reasonableness of the goals in terms of cost, weights, and feasibility of achieving the required noise reduction. Based on this assessment it may be required to reduce the noise of other components with levels close to the goal if it is not feasible to achieve the required level or if the cost or weight impact is too high.

For intermittent noise sources, the process is more complex since more options are available. The first step would be to review the NC time history and attempt to reduce the levels above NC 40 in a manner identical to that outlined for continuous noise sources, realizing that the mix of noise sources would vary with time. The goal of this step would be to reduce the total time that NC 40 is exceeded. If that time cannot be reduced to zero, the next step would be to reduce the peak dBA level to comply with the limit corresponding to the total time NC 40 is exceeded. A procedure similar to that described above would be used to set goals for the peak dBA reduction, except that A-weighted spectra would be used.

5.0 PLAN FOR CONTROLLING NOISE EMISSIONS

The plan for controlling noise emissions will rely heavily on the data used for subrack allocation. Components making the largest contributions to the total noise will receive the most attention. Methods for reducing the noise at the source will be the first order of priority followed by attenuation of the noise along the transmission path and the use of vibration isolation to minimize structure borne paths. In addition to reducing the isolated component levels, increased absorption and transmission loss will be used to reduce the noise emission. Attempts will also be made to operate components, such as fans, at different rotational speeds to eliminate the possibility of tones from these fans combining constructively. For intermittent noise sources, the total noise can be reduced by not operating noisy components simultaneously. This option will be examined.

5.1 Source reduction.

Reduction of the noise levels at the source can be achieved both by selection of low noise and low vibration components and by operating these components at the quietest operating condition compatible with mission requirements. Components that have the potential to be significant contributors to the total noise of a rack are fans, motors, pumps, disk drives, flow valves, and fluid flow. Following are examples of possible approaches that can be used to minimize the noise of these components.

Fan noise:
- Minimize turbulence and flow distortions entering the fan.
- Maximize the spacing between the rotor and any object either upstream or downstream of the rotor.
- Reduce the fan speed.

Motors:
- Reduce motor speed.
- Avoid structural resonances due to fluctuating magnetic fields.

Flow valves:
- Reduce pressure drop.
- Use low noise valves.

Flow noise:
- Reduce flow velocity.
- Avoid sharp corners and sudden area changes.

The above list is by no means a complete compilation of all potential noise reduction guidelines, but has been included to show that several approaches are available to reduce the noise of the potential major noise sources. The most significant challenge in noise reduction is to reduce the noise of a component without compromising the required function of that component.

5.2 Increased absorption.

Use of acoustic treatment within the FCF will also be considered for noise reduction. When noise is generated within a confined space a reverberant sound field is produced with an average sound pressure level given by:

$$SPL_{AVG.} = PWL + 10*LOG(4/R_{CE})$$

Where

PWL is the sound power of the source, dB.
R_{CE} is the room constant of the enclosure.

$$R_{CE} = S\alpha/(1-\alpha)$$

Where

S = surface area
α = average surface absorption coefficient.

The effect of the enclosure is to cause the level within the space to increase to the point that the energy transmission through the walls of that space equals the noise generated. Acoustic treatment increases the value of α , decreases the level of the reverberant field and hence decreases the noise transmitted. The benefit of increased absorption within an enclosure is illustrated in Figure 6(taken from the third reference listed in paragraph 2.2 of this document), which shows the benefit of increased absorption on the insertion loss of an enclosure with 1% acoustic leakage. Insertion loss is the difference in sound pressure level at a particular location before and after acoustic treatment is applied. A benefit of about 10 dB is obtained at high frequencies by increasing the absorption coefficient within the enclosure from 0.1 to 0.9.

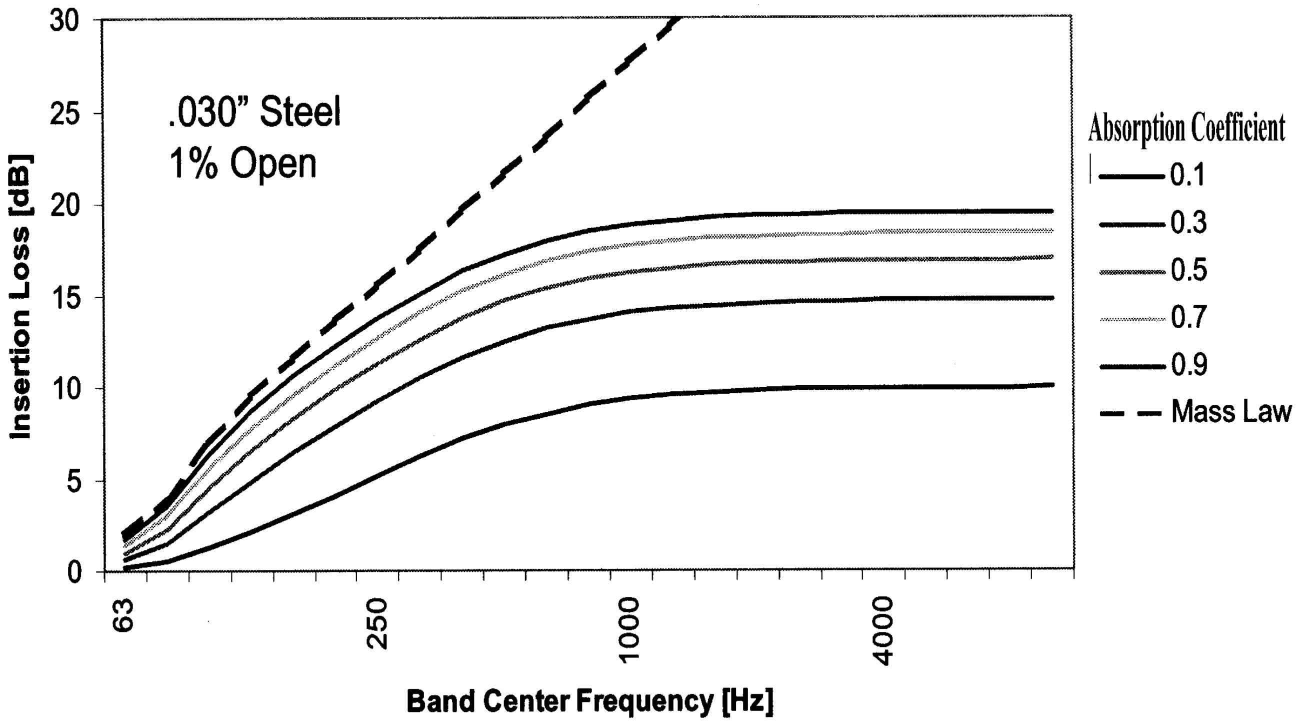


FIGURE 6. Benefit of increased absorption coefficient

To maximize the effectiveness of acoustic treatment and to minimize its weight, it is important to match the design of this material to the spectra of the noise within the volume. Thus, an important part of the noise control process is to obtain detailed noise spectra from the noise generation components. Sources controlled by high frequency content will require much thinner and lighter absorption material than sources controlled by low frequency content. Spectral data on each noise significant source will be obtained both as an isolated source and installed within the rack.

5.3 Increased transmission loss.

Increasing the transmission loss through the FCF cabinets will also reduce the emitted noise by increasing the insertion loss due to the enclosure. However, this approach is likely to be the most costly in terms of weight since transmission loss is strongly dependent on the mass per unit area[2]. Two key aspects of the benefits of increased cabinet transmission loss are: the need for absorption within the rack and the need to minimize any acoustic leaks. The effect of absorption on the insertion loss of an enclosure was discussed previously in paragraph 5.2.

Small opening or cracks in an enclosure result in acoustic leaks and can significantly reduce the transmission loss of a structure. This effect is illustrated in Figure 7 (taken from the third reference listed in paragraph 2.2 of this document), which shows the effects of leakage on the overall transmission loss of an enclosure. As can be seen, the composite transmission loss is significantly reduced as the amount of leakage (% open) increases. The negative effect of leaks can be even more severe in the vicinity of the leaks. Thus, key aspects of the noise control plan are to minimize leaks during the design process and to take sufficient measurements during testing to determine if any significant leaks exist.

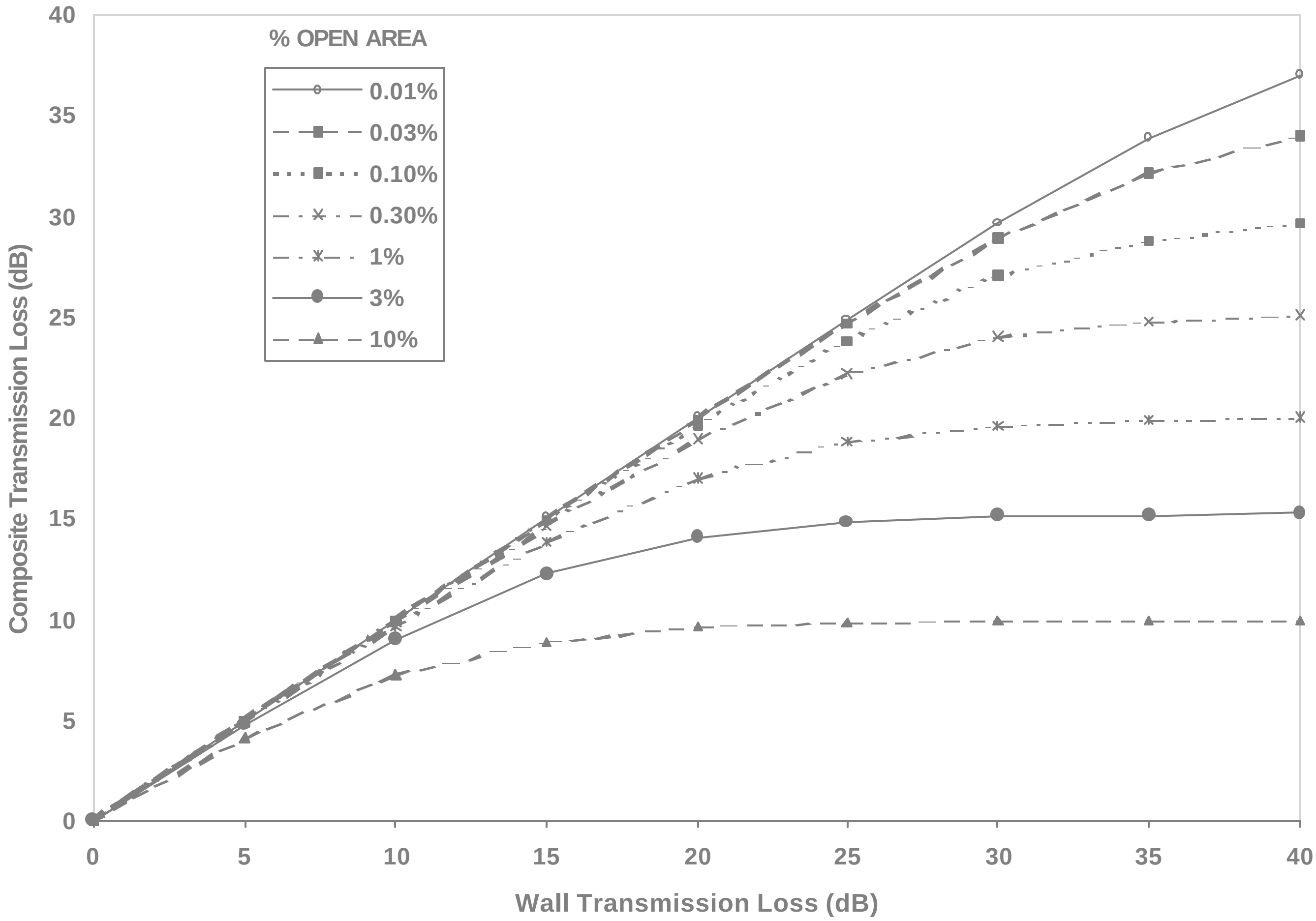


FIGURE 7. Effect of leakage on transmission loss

6.0 ACOUSTIC DATA FOR VERIFICATION

6.1 Initial acoustic verification.

Preliminary acoustic analysis data will be submitted as part of the Payload Unique ICD for each integrated rack within the FCF. These data will include noise emitted from the worst-case continuous noise source and the worst-case intermittent noise source. Data for continuous-type noise sources will be octave band sound pressure levels (SPL) for the 63, 125, 250, 500, 1000, 2000, 4000 and 8000 Hz octave-band frequencies. Linear overall and A-weighted overall levels will also be provided. For intermittent-type noise sources, A-weighted overall levels will be provided. To the extent possible, these data will be obtained in a very low background noise environment. Background noise levels will also be provided.

These data will provide a preliminary assessment as to whether each integrated rack meets the noise requirements. These data will also be used to identify potential problems and to assist with the implementation of additional noise reduction measures.

6.2 Final acoustic verification.

Final data for flight certification will be obtained in the NASA Glenn Acoustic Testing Laboratory. This laboratory, estimated to be operational by late calendar year 2000, will have the capability to be operated as either a fully anechoic facility or as a hemi-anechoic facility by removal of the wedges on the floor. The laboratory is designed to have the following properties:

- Very low background noise levels. All test support equipment is to be located outside of the test chamber.
- Large, empty test volume with absorptive surfaces to provide either a full or a semi-anechoic environment (100 Hz low frequency cutoff).
- Automated multi-channel data acquisition system.

Acoustic data will be acquired with Bruel and Kjaer microphones and preamplifiers present in the GRC lab. Acoustic data will be analyzed using National Instrument Sound Power System, which can provide narrow band, 1/3 octave, and octave band spectral data, plus A-weighted sound pressure levels. The system is Type 1 compliant. Software to compute sound power levels is included and sound power levels will be obtained consistent with ANSI S12.35-1990 (the fourth reference listed in paragraph 2.2 of this document.

The Final Acoustic Verification Report will provide data: (1) to verify that each rack meets the specified acoustic requirements and (2) to be used to perform acoustic noise analysis of the integrated module. A complete description of the test setup, room characteristics, and operating conditions will be provided. Sufficient data will be obtained to identify significant noise sources and radiating surfaces. SPL data will be provided for the loudest point on each side of the integrated rack for each operating mode for which acoustic data are required. Data for continuous noise sources will be octave band sound pressure levels for the 63, 125, 250 500, 1000, 2000, 4000, and 8000 Hz octave frequencies. Linear and A-weighted overall levels will also be provided. For intermittent noise sources, A-weighted overall levels will be provided. Background levels will also be measured. If analytical methods are used to determine noise levels, the report will describe how the method was test validated.

Acoustic noise emission tests will be performed with the test article configured and operating in each of the operational modes that will occur on orbit and that will result in significant noise emission. All testing will comply with SSP 57010B, Appendix D, Acoustic Noise Control Plan.

7.0 RECOVERY PLAN

An important part of the recovery plan is the detail of data obtained in the final verification test. Attempts will be made to isolate the noise from the individual components and from the various radiating surfaces to isolate the cause of exceeding the requirements. Detailed data, such as narrow band spectra, can be used to determine if tones are present in the spectra to determine if structural modes are being excited. If this is the case, appropriate damping or changing the structural resonant frequencies may help to alleviate the problem. Likewise detailed directivity measurements or intensity measurements can be used to determine sources of sound emission. These data can be used to locate poor seal resulting in high radiation or the lack of adequate transmission loss through rack surfaces. Diagnostic testing, such as simultaneous internal and external noise measurements, accelerometer measurements, measurements with and without acoustic treatment, and sequential operation of individual subrack components can be invaluable in determining the cause of the excess noise. Advanced data analysis techniques, such as cross-correlation and cross-spectra, may also prove useful.

Once the cause of exceeding the requirements is identified, one or more of the following approaches will be used to alleviate the problem:
- Modify or replace noisy components with quieter versions.
- Review and change component operating parameters to reduce noise.
- Review and modify time sequence of tests to minimize the number of noisy components operating simultaneously.
- Redesign absorption material to better match spectra of source or to increase absorption coefficient.
- Add vibration isolators to minimize structure borne noise paths.
- Dampen resonating surfaces detected to be noise sources.
- Seal leak.
- Increase transmission loss of rack.

APPENDIX A ACRONYMS, ABBREVIATIONS, AND SYMBOLS

A.1 Scope.

This appendix lists the acronyms, abbreviations, and symbols used in this document.

A.2 List of acronyms, abbreviations, and symbols.

ARIS	Active Rack Isolation System
ATCU	Air Thermal Control Unit
CIR	Combustion Integrated Rack
dB	Decibel
dBA	A-weighted Decibel
ECS	Environmental Control System
EPCU	Electrical Power Control Unit
FCF	Fluids and Combustion Facility
FIR	Fluids Integrated Rack
FOMA	Fuel/Oxidizer Management Assembly
GRC	Glenn Research Center
Hz	hertz
ICD	Interface Control Document
IOP	Input/Output Package
IPP	Image Processing Package
ISS	International Space Station
m	meter
NASA	National Aeronautics and Space Administration
NC	Noise Criteria
PI	Principal Investigator
PWL	Acoustic Power Level, re $1x10^{-12}$ W
R_{CE}	Room constant, M^2
S	Surface area, M^2
SAR	Shared Accommodations Rack
SPL	Sound Pressure Level, re 20μPa
UML	Universal Mounting Location
US Lab	United States Laboratory Module
WTCS	Water Thermal Control System
α	Absorption coefficient

APPENDIX B PRELIMINARY ACOUSTIC TIMELINE FOR THE FCF

B.1 Scope.

This appendix outlines the preliminary FCF Acoustic Timeline.

B.2 Timeline.

On All Times

IOP hard drive
ATCU fans
WTCU water flow
PI-specific avionics (allocation only no testing)

On During Pretest

IPSU
WTCU valves open and close
FOMA valves open to deliver gas supply for chamber atmosphere
FOMA valves close once chamber fill is complete
Camera alignment involving the servo motors
GC analysis of atmosphere-pump
Chamber fan

On During Test

IPSU
WTCU valves open and close
Camera alignment involving the servo motors
FOMA valves open and close during test

On for Posttest

IPSU
WTCU valves close
GC analysis
Exhaust vent clean up
FOMA valves open and close